Dr. Hoye

TECHNICAL REPORT
71-8-FL

THE FEASIBILITY OF CONTINUOUS HEAT STERILIZATION OF FOOD PRODUCTS USING MICROWAVE POWER

by

E. M. Kenyon

November 1970

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

U.S. ARMY MATERIEL COMMAND

FOOD LABORATORY

FL 118

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FOREWORD

A continuing program is being conducted at U.S. Army Natick Laboratories directed toward replacing the rigid, cylindrical tin-can with a flat plastic pouch for products in individual Army rations. These efforts have resulted in an aluminum-foil film laminated pouch, heat-sealed, and processed by means of steam under pressure in a batch-type sterilizer.

This report outlines the feasibility of using microwave energy on a continuous basis to accomplish heat sterilization of food products in plastic film laminated pouches. It describes previous work done by other investigators, describes a pilot processor which has been designed, built and operated successfully and outlines a process for sterilization, holding and cooling of plastic laminated pouches containing food products such as chicken ala king and frankfurters.

The objective of this study is to achieve improved ration component quality in terms of flavor, texture and appearance and obtain the economic benefits of continuous processing. Much of this work was reported at the Annual Meeting of the Institute of Food Technology at San Francisco, California, May 1970 and a paper is scheduled for publication in the Journal of Food Science.

Acknowledgment is made to significant technical contributions made in these studies by Mr. Philias Lacasse, GEPL and Mr. James W. Gould, Food Laboratory.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Potentially, microwave power offers an opportunity to achieve a continuous and very rapid method of heat sterilization for food products. The capability of attaining temperatures of 250°F (121°C) or above in a matter of about five minutes as opposed to the present 50 to 60 minutes in a steam retort is expected to result in a product with greatly improved texture and flavor. In addition, there should be economies in the operation.

Previous work is reviewed briefly and the problems basic to the application of microwave power in food sterilization are discussed.

A continuous system for the thermal processing of food in plastic pouches has been developed in which over-riding air pressure is used to balance internal pressure and prevent pouch rupture. The pouches are filled with 6 to 8 ounces of food product, heat-sealed and introduced through an air lock onto a conveyor inside a 5-inch i.D plastic (epoxy fiberglass) pipe which is located within a (Litton Model C-10S-2) microwave conveyor cavity. Microwave energy is supplied by four modular units generating a total of 10 kW at 2450 MHz. Conveyor speed and power level are regulated to provide the desired process time and temperature. Pouch cooling is accomplished either by a refrigerated platen under the final section of the conveyor or by immersion in a cold water reservoir. Pouches are over-packed after processing, in a barrier film (aluminum foil-plastic) laminate to provide protection and storage stability.

Several food products including frankfurters and chicken ala king have been processed in order to evaluate the system.

Design and performance data are discussed and an evaluation is made of the future potential, both from the technical and economic points of view.

INTRODUCTION

A number of present and planned Army operational rations are being designed around the concept of food packaged and sterilized in flat, rectangular flat seal design, plastic-laminate pouches as a replacement for the conventionally canned items. FIGURE 1 is a photograph of three pouches showing typical products now being investigated for use in these experimental operational rations. The photo shows the relative size and general configuration of the pouches.

A study was conducted to determine the feasibility of accomplishing sterilization of food items in pouches similar to these using microwave power. The goal was improved texture, flavor and a generally higher quality product over those produced by present steam or water retort methods.

The rapid, continuous process as opposed to the batch process is generally the goal of the process design engineer. It usually offers economic advantages and in most cases for food products rapidity of heat treatment, will improve product quality by eliminating long time cooking or processing times. Microwave power offers an opportunity to achieve both of these objectives of short time, continuous processing.

The essentials of such a system are: 1) a container which is relatively transparent to microwave energy, retains its strength at sterilization pressures and temperatures, can be hermetically sealed, and will resist recontamination of the product subsequent to sterilization; 2) a method of introducing microwave energy efficiently into the food product within the container in order to achieve sterilization temperatures for the required times; 3) a method for conveying the container and its contents through the microwave field.

If container materials relatively transparent to microwave energy were available capable of withstanding the internal pressures developed at the temperatures necessary for food sterilization and easily sealable, preferably in automatic machinery, the problem would be a relatively simple one. Unfortunately, at the present time, this is not the case. Transparency to microwave energy generally is associated with non-metallic, organic-polymeric materials (plastics), or the glasses and inorganic materials of that class.

Examination of the literature of the dielectric characteristics of materials indicates many materials which are relatively transparent and might be candidates for containers for such a process. However, few of these materials meet the second two requirements of being easily sealable and able to withstand the internal pressures at the temperatures required for food sterilization. Table 1. indicates the typical destruction times of various bacterial spores, which is the most heat resistant form of any micro-organism.

As can be seen, all but a small class of organisms, namely thermophiles, are essentially destroyed at temperatures of 250°F and above at times of 1 to 10 minutes. Commercial practice would generally indicate a temperature of at least 250°F for 3 to 4 minutes would give "practical" sterilization.

As the temperature within a hermetically sealed pouch containing food product with an appreciable water content is raised above 212°F, the pressure due to steam generated will rise predictably, and at 250°F an internal pressure of approximately 15 psi gauge will prevail.

A film or laminate of films must be selected which will not soften at temperatures around 250°F for periods of from 3 to 4 minutes. This softening is particularly critical around the heat-sealed seams (generally used to fabricate such pouches in order to minimize rupture due to the internal pressure at the seams) which are generally the weak points in the package.

Studies have been conducted (Gould _et al_, (1), Hu _et al_, (2) and others) which have shown that foods can be successfully heat processed in steam or water retorts if air over-pressure is used during heating and cooling. It seemed reasonable to employ an air over-pressure to counterbalance the internal pressure developed in microwave processing.

Future studies are planned with respect to the most suitable films or film laminates for use in microwave processing, but preliminary experiments showed that a laminate of Mylar-polyethylene-polyisobutylene behaved reasonably well with respect to sealability, seal and package strength under pressure, and transparency to microwave energy. Since the main objective of this study was the engineering system feasibility, this film laminate has been used to date and has proven to be reasonably satisfactory.

The need for an air over-pressure introduced a fourth essential to the processing system, namely - that the entire conveying system within the microwave cavity would need to be pressurized on a controllable basis. In addition, if the system were to be continuous a method of getting the pouches in and out of the pressure system, and for cooling the pouch to 212°F or below before removal needed to be devised.

While the application of microwave energy to the heating of food materials is relatively new, there is a surprisingly small body of open literature available on the concept of sterilization of foods in hermetically sealed containers on a continuous basis using this form of heat input. This may be, in part, explained by the fact that while work may be underway in this field, much of it may be of a proprietary nature. Certainly the bulk of the literature has appeared as patents.

Pasteurization of liquids and surface inhibition of micro-organisms has been more adequately described. Decareau (3) recently summarized the present state of the art in both sterilization and pasteurization.

True sterilization in containers either prior to or after hermetic sealing was discussed by Jackson (4) who also summarized earlier work. Most studies were conducted at relatively low frequencies compared to present standards. The work of Jackson and others was done in glass containers of various types including baby food jars, and were primarily batch experiments. Jackson discussed problems encountered including local heating, arcing and burning, rupture of containers and suggested the use of higher frequencies than those previously used.

Landy (5), discussed a batch process in which the food material could be sterilized in both glass and plastic tubes in a batch process by use of microwave energy. Mention was made of the use of a rigid form in some cases to maintain constant volume of the flexible containers used. Thus, a counterbalance to internal pressure is necessary to attain practical sterilization temperatures.

Long (6), discussed a method by which food products could be sterilized by microwave energy on a continuous basis in plastic pouches. In this case, the pouch was open to the atmosphere during the heat treatment and subsequently sealed. A labyrinth-type opening in the pouch was designed to preclude the entry of micro-organisms during the process. This method was limited to those products which could be sterilized at 212°F.

Jeppson *et al.*(7), discussed a continuous method of sterilization of foods in which a hydrostatic pressure system was used to maintain the hydrostatic head (and hence over-pressure for materials in flexible plastic pouches), and a heating section filled with mineral oil to provide a non-lossy medium for the product.

Jeppson (8), further discussed continuous microwave processing of skim milk (in 8-ounce glass jars) and heat-sensitive fruits using conveyorized ovens.

EXPERIMENTAL

The Process

The process involves passing food packaged in sealed plastic pouches through a microwave energy field on a continuous basis to achieve a sterilization temperature. This is followed by cooling of the pouches and a subsequent aseptic overpackaging with a suitable plastic-foil laminate to afford adequate storage and handling protection of the product.

The equipment used to accomplish these objectives was designed to provide an experimental machine as inexpensively and as simply as possible in order to establish the feasibility of the process and to study the quality of the resulting product. No attempt was made to refine the design or to provide sophisticated automation, although design features were selected which would permit future refinement.

Equipment

1. *Chamber* - The principal component of the system is a 25-ft. long cylindrical fiberglass reinforced epoxy tube. A metal (aluminum) box at each end contains the drive and idler mechanisms of the conveyor system and other accessory devices. Fiberglass epoxy was chosen as a tube material because of its strength at elevated temperatures and its relative transparency to microwave energy. The dimensions of the tube were dictated by:

   a. The dimensions of the microwave cavity available.

   b. The pouch size (the standard pouches are approximately 4 1/4 by 7 by 1/2 inches.

   c. Availability of standard pipe.

The commercially-available pipe selected was Chemline* with the following characteristics:

Epoxy Fiberglass Tube Characteristics

Outside diameter	4.580 inches
Inside diameter	4.360 "
Wall thickness	0.220 "
Maximum pressure-temperature rating	150 psi at +300°F

Standard flanges and sleeves were used with the pipe to permit attachment of the pipe to the end boxes and to assemble sections of pipe in order to permit disassembly of the system from the microwave cavity if desired. Figure 2 shows a sketch of the complete system. The letter - F, is the fiberglass epoxy tube passing through the microwave oven unit. Letters - G, K, and D are the aluminum end boxes constructed of 3/8" aluminum plate with appropriate openings to accept the tube, the entrance valve system A-B-C and the receiver chamber. Letters - L, E and J, are view and access ports to the end boxes.

2. Valve System - In order to pass the pouches in and out of the pressure system some type of valve arrangement was necessary. Various devices were considered including rotary valves, barometric legs and several special designs. An air lock arrangement was finally adopted which utilized a standard, commercially-available butterfly valve** A wafer-type, hand lever-operated, 6" I.D. valve rated for 50 psi shut-off service was used. The entrance system utilized two of these valves to provide an air lock system. FIGURE 3 shows a cross-sectional sketch of the valve system with a section of tube.

The valve is mounted at an angle to the horizontal of approximately 45 degrees into the feed box end of the pressure system as shown. In this way, the pouch slides by gravity through the air lock assembly G. During operation, the lower section of the assembly (attached to the end box F) is under system pressure (15-18 psi) and the lower B valve is shut. The pouch is introduced into the upper section at A. The first valve B is opened, and the pouch slides into the first chamber G.

*Dow Smith Inc., Little Rock, Arkansas
**Rockwell Manufacturing Co., Pittsburgh, Pa.

The first valve B is closed, and the chamber between the two valves is pressurized by compressed air. When the pressure on both sides of the second valve B is equalized, this valve is opened and the pouch slides into the pressure system and is guided onto the conveyor K, by chute C, and guide H. The second valve B, is then closed, the first chamber is depressurized, and the cycle is repreated. Letter D, is the endless belt idler roller with screw take-up adjustment E. The polypropylene strip J, serves to support the belt within the tube. Letter -I, shows the flange attachment of the tube.

Refinements such as pouch positioning sensors, pressure transducers, and electric or hydraulic operation of the valves can easily be introduced to automate the system. It is planned to do this in future redesign of the equipment.

3. <u>Conveyor System</u> - In order to move the food pouches through the epoxy fiberglass tube, and hence through the microwave field, a continuous belt conveyor system is provided within the main pressure system. One-eighth inch thick strips of polypropylene were cut to a width slightly less than the internal diameter of the epoxy tube (approximately 4 inches wide and in lengths of approximately $4\frac{1}{2}$ ft). These strips were fastened together with flat head nylon bolts and laid within the epoxy tube to serve as a bearing surface on which the continuous belt rides. The belt passes over the top of the polypropylene surface and returns under it in the tube. The belt is a neoprene Typalon* (Chlorinated sulphenated polyethylene) coated polyester fabric material $3\frac{1}{2}$ inches wide and approximately 50 ft. continuous length. FIGURE 4 is a cross-sectional sketch of the end box of the system. A geared motor C, with suitable gear reduction druves a 4-inch drum G, with an idler roller F, providing approximately 80% wrap-around on the drum. The drive pulls the belt from the opposite end to the entrance feed box. The belt speed can be controlled from zero to approximately 7 ft/min by an appropriate speed control device. The drive motor C, is located within the end box eliminating the need for external shafting and pressure-tight bearings. The motor is 1/32 hp with a maximum operating temperature rating of approximately 200°F. Tension adjustment is provided for the belt to compensate for expansion and contraction under varying temperatures.

*MIL-C-13285 Type I Class I

4. Microwave Applicator - A model C-10S-2* microwave conveyor unit was available in these Laboratories. FIGURE 5. This unit had been used for several pilot studies and small scale production runs. It had proven to be highly reliable and previous studies had established the various energy distribution characteristics of the cavity. The main cavity is 9 ft. 7 in. long by 27 in. wide, by 26 in. high; however, the entrance and exit sections to the cavity are 5 in. high and 14 in. wide. It was not desired to reconstruct the unit so the 5 inch-dimension was the limiting one which determined the outside diameter of the epoxy tube which passes through the main cavity. The belt of the unit and its drive were not used, of course, since the epoxy tube contained its own conveyor system.

The microwave unit operates at a frequency of 2450 MHz and is powered by four water-cooled, modular, magnetron generators providing 0 to 10 kW average power in eight steps of approximately 1.25 kW. (Each module operates at 1.25 kW or 2.5 kW). This modular design offers flexibility of operation not obtainable with a single generator, giving advantages which have been discussed by Gerling (9).

One of the principal advantages of a conveyor type system which moves the product through a fairly long cavity is the evening-out of non-uniformities of electromagnetic field strengths which always exist in a cavity applicator no matter how skillful the design. The product in this situation is subjected to a uniform dose of energy during its travel through the cavity.

Another advantage of this microwave unit is the provision of water loads in the entrance and exit sections of the main cavity which permit operation of the unit with small loads in the cavity, e.g., a few food pouches at a time, if desired, without damage to the generator tubes.

COOLING

After sterilization the food pouches must be cooled to at least 212°F in order to reduce internal pressure prior to removal from the pressure system. In any production operation this can be accomplished

*Litton Industries, Atherton Division, Minneapolis, Minn.

by incorporating a cooling section within the pressure system in which the belt conveying the pouches passes over a cooling platen prior to discharge from the system. Experiments were conducted and preliminary design data have been collected to permit the addition of a cooling section in the process system at a later date. For the present experiments (FIGURE 4) a receiver chamber K, utilizing cooling water L, on an emptied batch basis is being employed through valve H. In either case, pouch temperatures can easily be reduced from the process temperature (250°F) down to 212°F in approximately 3 to 4 minutes, or less.

PACKAGING

The process described is designed to sterilize solid or semi-solid food products sealed in flexible, plastic film-laminate pouches. In these experiments the pouches were heat sealed on three sides, filled with approximately 6 to 8 ounces of product and the fourth side heat-sealed.

Since no known solely plastic laminate will provide the physical and microbiological protection to the food product after processing, particularly when subjected to the rigors of the military supply system, an overpack was considered to insure physical protection and storage stability. The present experimental military foil laminate (3 mil polyolefin -0.35 mil aluminum foil -0.5 mil polyester) was considered suitable for this purpose.

Overpackaging, however, introduces the problem of possible bacterial contamination between the outer surface of the pouch and the inner surface of the overpack resulting in possible contamination and subsequent spoilage of the product. To obviate this problem, sterilized pouches can be removed from the cooling receiver aseptically and overpacked with a sterile pouch in a "clean" environment (box or clean area). They could be passed directly into a sterile environment and overpacked with sterile pouches on a continuous basis. FIGURES 6 and 7, are photographs of the entrance valve assembly showing the epoxy tube in the microwave cavity. FIGURE 8 is a photograph of the microwave cavity with tube. FIGURE 9 shows the end exit box, and FIGURE 10 shows the exit box with the cooling receiver attached below the box.

TABLE 2 shows the performance characteristics of the continuous reactor. The feed rate and other variables shown are based on continuous individual hand operation and are not intended to represent

potential continuous production rates or capabilities, but rather to indicate the engineering characteristics of the pilot processor.

Temperature Measurement - In order to achieve sterility and consequent bacteriological stability in the food pouches, it is necessary to achieve temperatures of 250°F or greater in all portions of the food and to hold these temperatures for an equivalent of at least 3 minutes.

The measurement of temperature of the food presents two problems. The first is that of measuring the temperature of individual pouches in a continuous process, particularly in a closed pressure system. The second is measurement of temperature without the use of a measuring device containing metal. Copson (10), discussed the second problem and various approaches to low-loss thermometry. No satisfactory answer has been developed with respect to the first problem although infrared detection techniques hold promise for measuring at least surface temperature of the pouch.

In preliminary work, paper strip thermometry was used. Chemically treated paper strips alone or sealed into small glass tubing were employed. These are available in 10°F increments and are essentially maximum and irreversible indicators which change from a light grey to a jet black color when their temperature rating is exceeded. Strips taped to the pouch surface, tubes with the paper sealed inside, or strips sealed in plastic and inserted into the food were used. These indicators have been shown to be useful and practical for the initial studies which were carried out.

RESULTS:

Limited product studies have been conducted with the continuous microwave processor described above. Typical heating curves for water and two products; chicken ala king and frankfurters, are show in FIGURE 11, which demonstrate the feasibility of the process. As would be expected, those products which were fluid in nature, permitted convection heating within the pouches (e.g., chicken ala king vs frankfurters), had a shorter heating time. Process times included a heatibg phase of 4 to 6 minutes as shown, approximately 3 minutes holding at process temperature (250°F or above), and a cooling period of 2 to 5 minutes for a total process of 9 to 14 minutes, which was close to the original design process contemplated. These times were obtained with an initial temperature of 75°F. Using a hot fill (150-160°F), which would be normal practice much shorter times to reach 250°F or above could be expected.

Economics -

Studies with the microwave system described above have not been conducted to a point where any valid estimates of economic factors can be made. The literature affords some very rough estimates as to potential costs and efficiencies for similar, but not identical, processes. Pollak et al.(11), studied comparative heating efficiencies of a microwave vs a conventional electrical oven, and concluded that the overall electrical efficiency of the microwave oven was 33.4% and of the conventional oven 36.7%. Crapuchettes (12), indicates a moderate increase in cost using microwave vs deep fat frying for potato chip processing. Using microwave energy, costs were less than 2.8 cents/pound. Commercial estimates for amortization of microwave equipment were 1.0 cent /pound.

Fetty (13), estimates costs for bread baking, thawing, and refreshening using microwave energy at approximately 0.002 cents/pound. EIMAC-Varian Associates (Staff Ed.)(14), estimate a 20,000 pound/shift continuous microwave processing system for cooking chicken to be amortized over a 3-year period but does not give cost data. Robe (15), studying pasteurization of wine and beer at a flow rate of 4 gpm. estimates costs at 0.1 cent/gallon. Jeppson (16), estimates process costs for sterilization of non-acid foods at 0.4 - 0.8 cents/pound,

It can be seen that estimates vary from less than 1 cent/pound to 2.8 cents/pound for various continuous microwave processes. These appear to be in an acceptable range, especially if a high quality and acceptability of product are obtained.

CONCLUSION:

A continuous microwave device was designed, constructed, and tested. Initial trials with food products packaged in flexible plastic pouches demonstrated process feasibility and process times which approached the design parameter. More extensive product quality studies, microbiological criteria, economic evaluation, and improved design features are currently in progress, and will be subsequently reported.

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FIG. 1: Pouches containing typical food products showing relative size and general configuration of pouches.

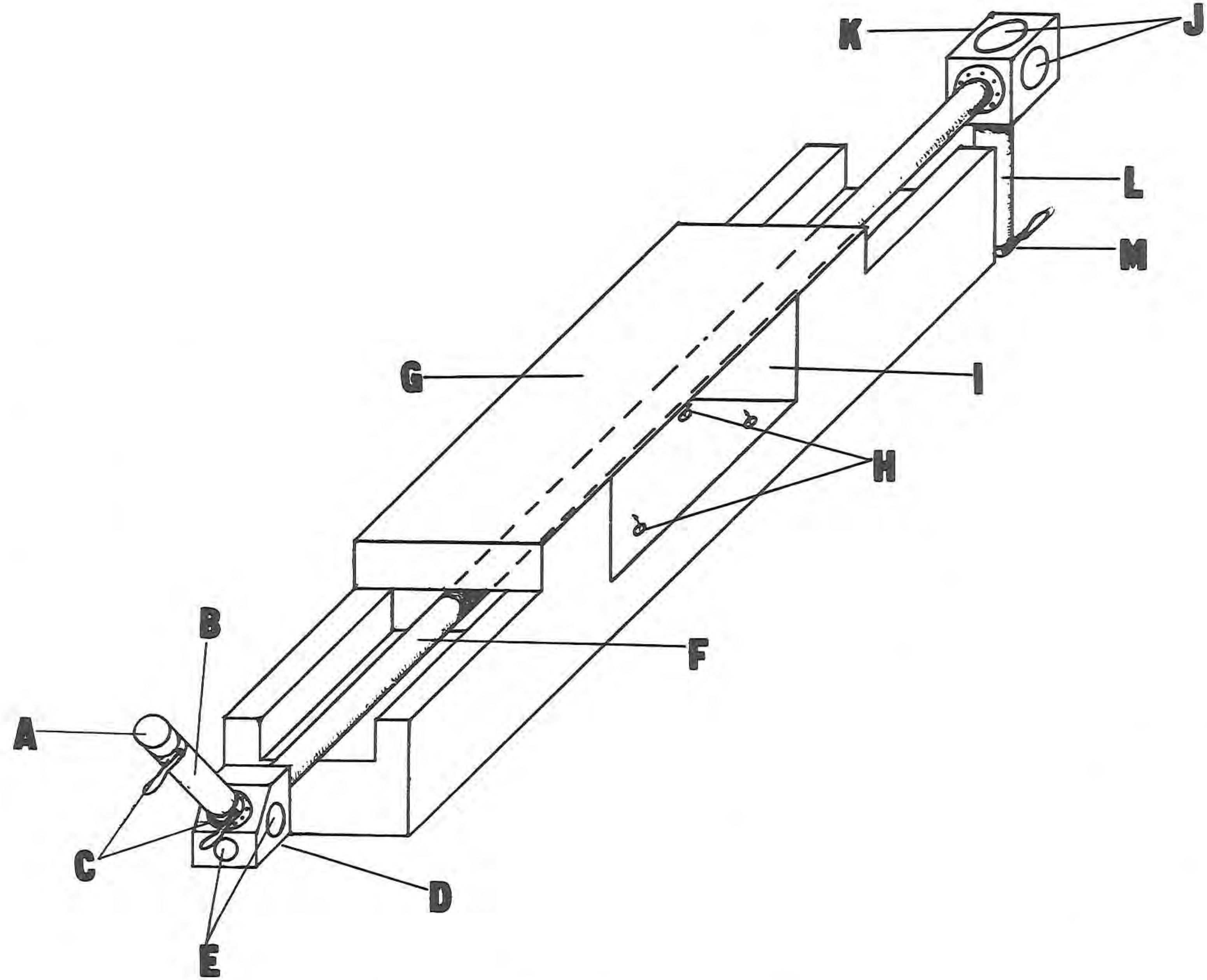

FIG. 2: Schematic drawing of microwave processing system.

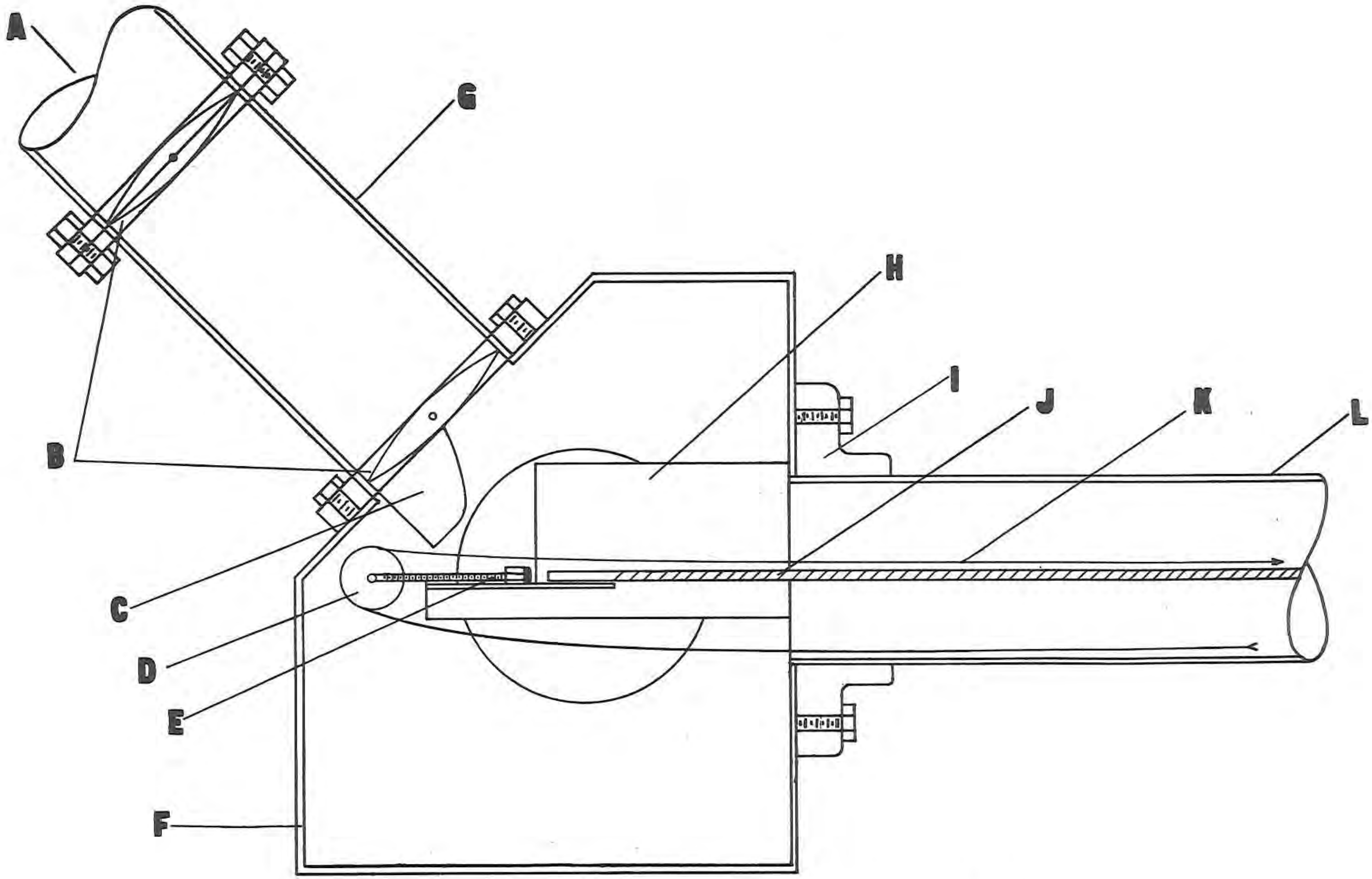

FIG. 3: Cross-sectional sketch of valve assembly at feed end of system.

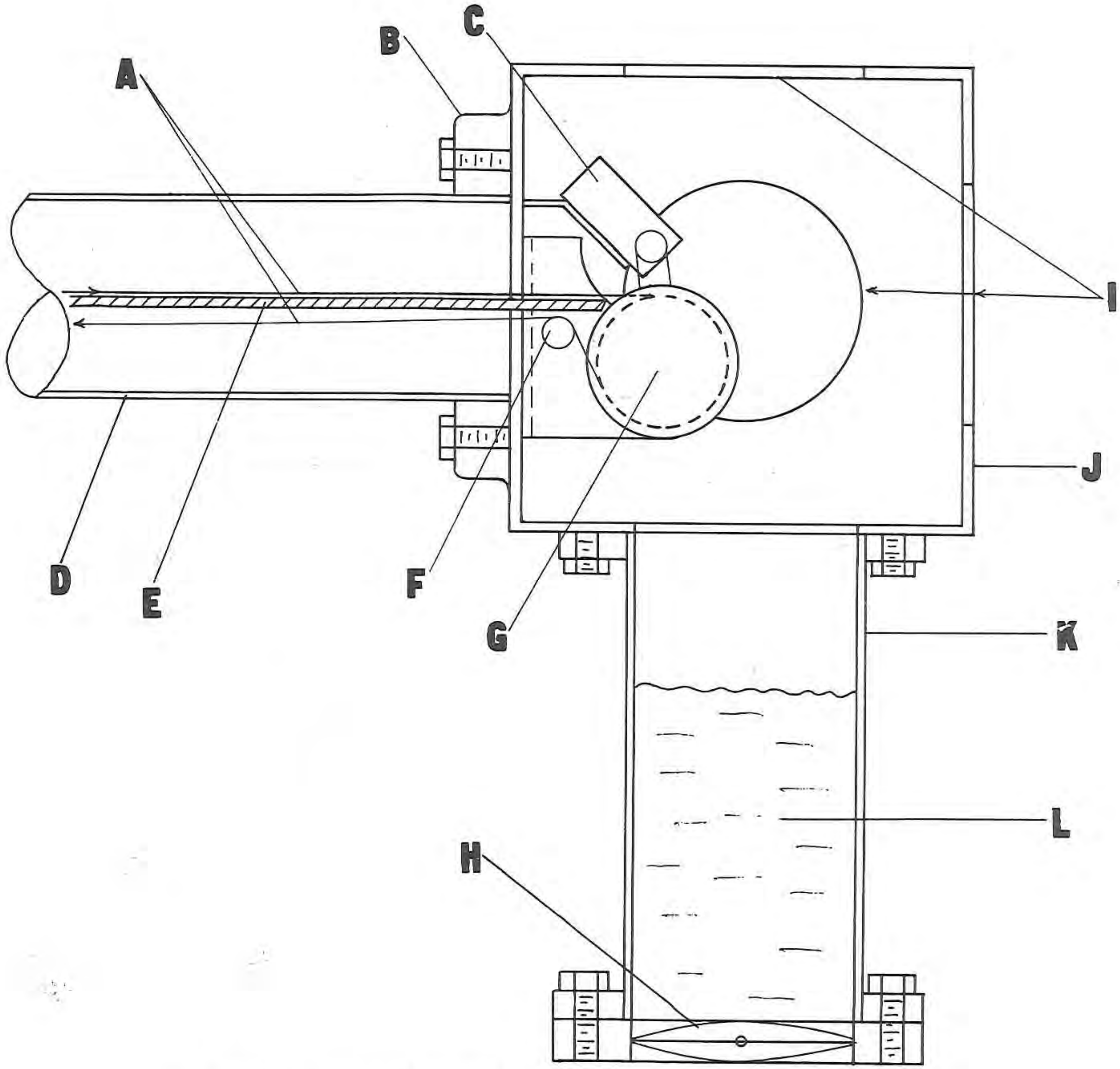

FIG. 4: Cross-sectional sketch of exit end of system with cooling receiver.

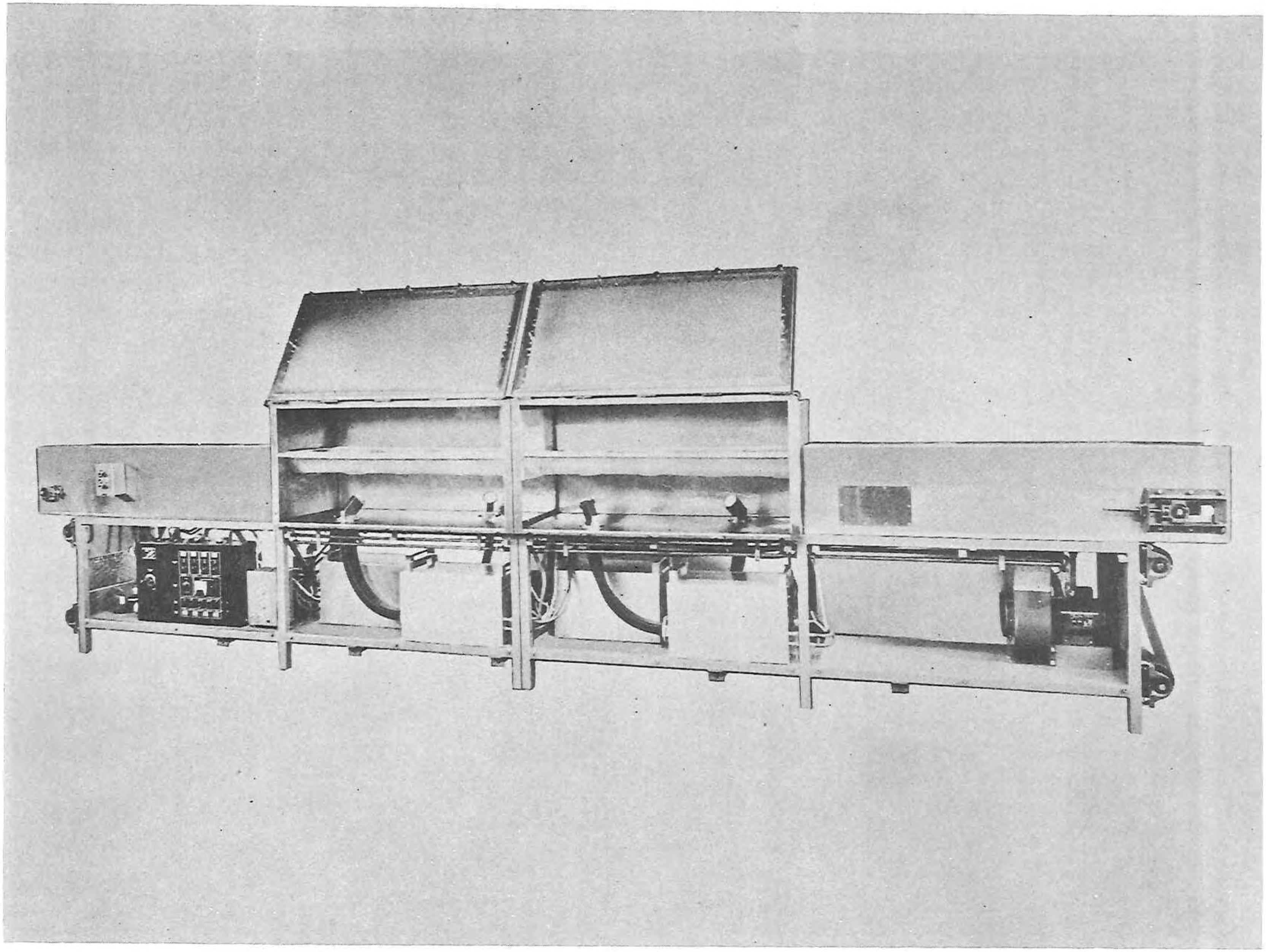

FIG. 5: Microwave applicator (Litton Model C-10S-2 Microwave conveyor.

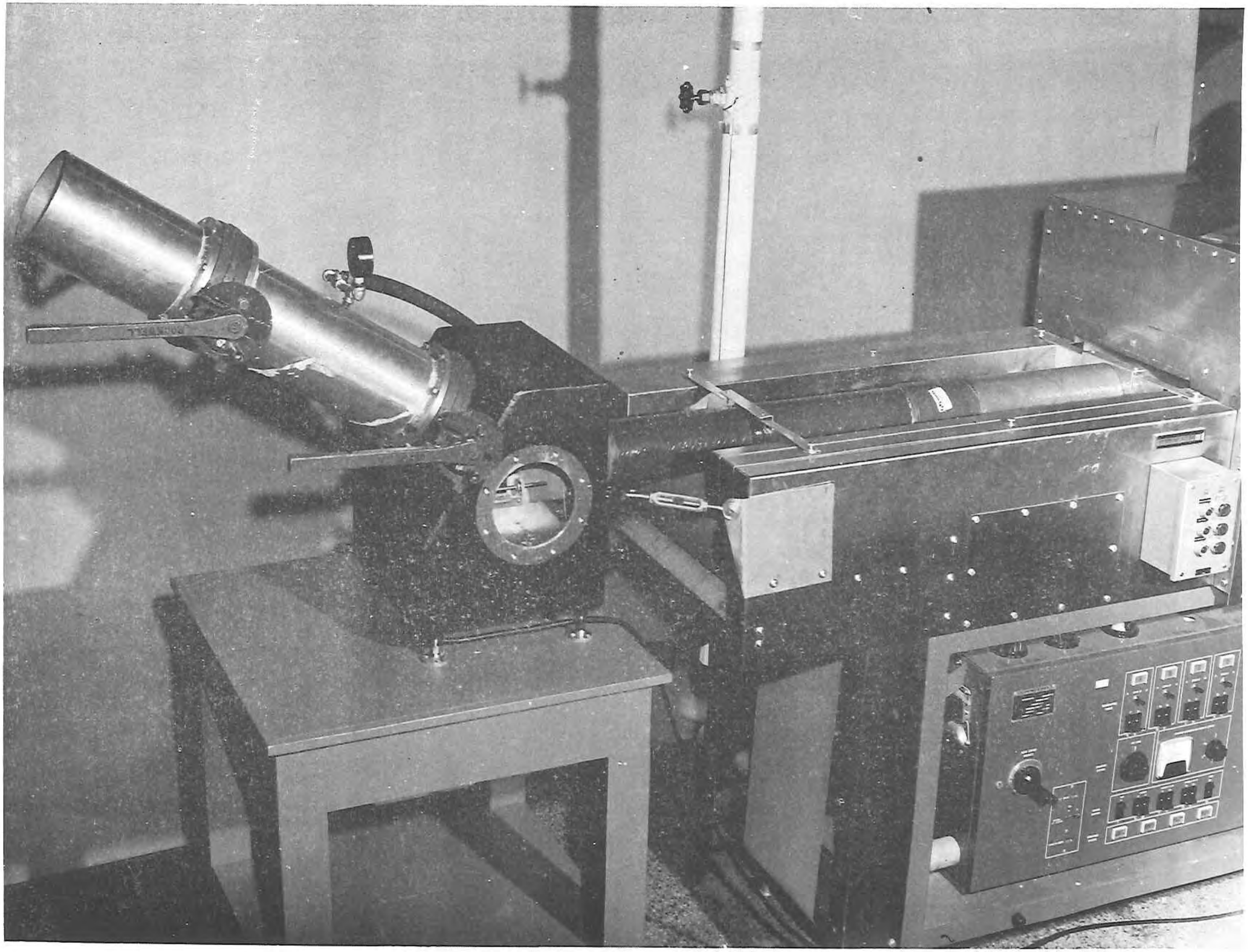

FIG. 6: View of feed end of microwave processor showing valve assembly and epoxy tube from outside.

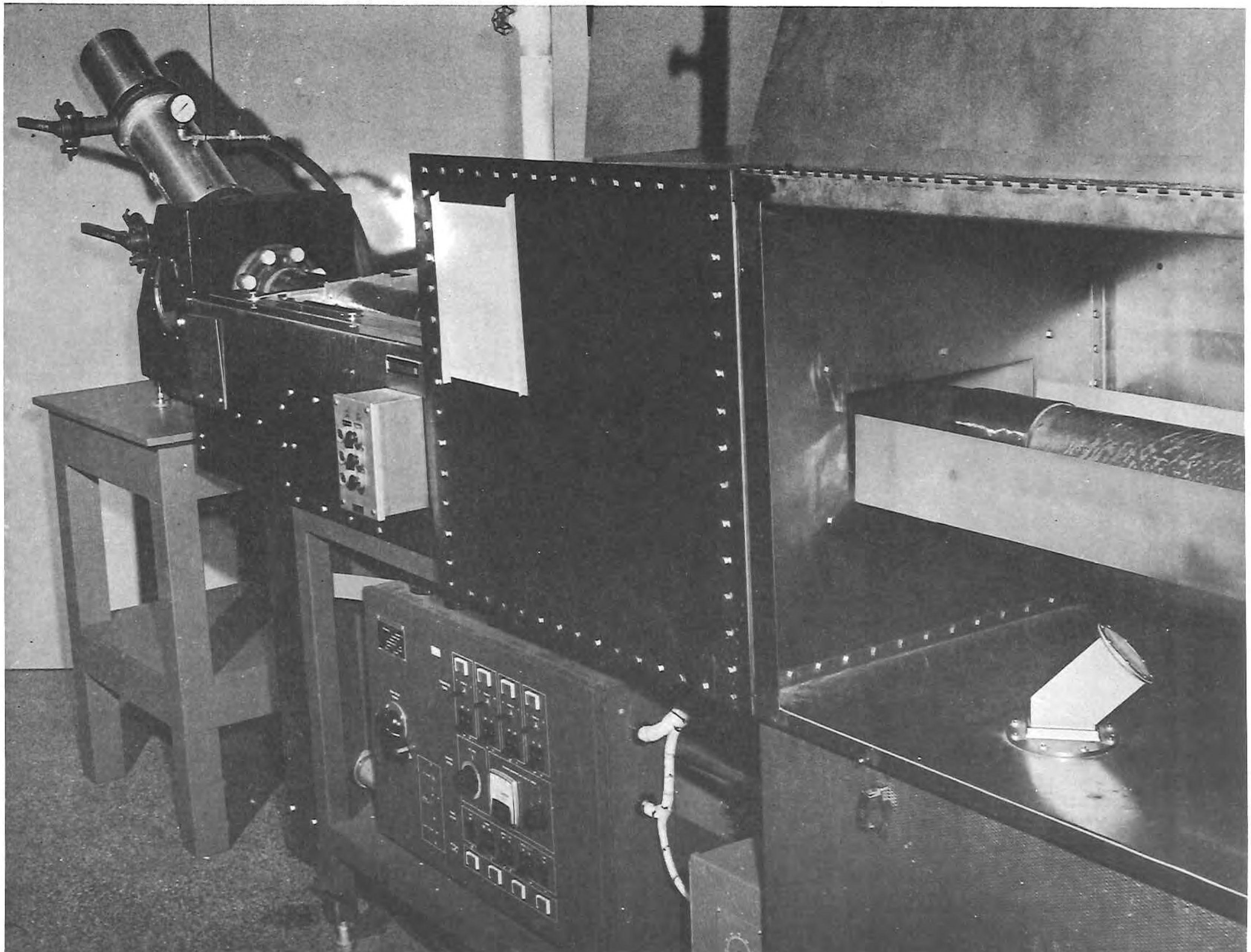

FIG. 7: View of feed end of microwave processor showing valve assembly and epoxy tube in cavity.

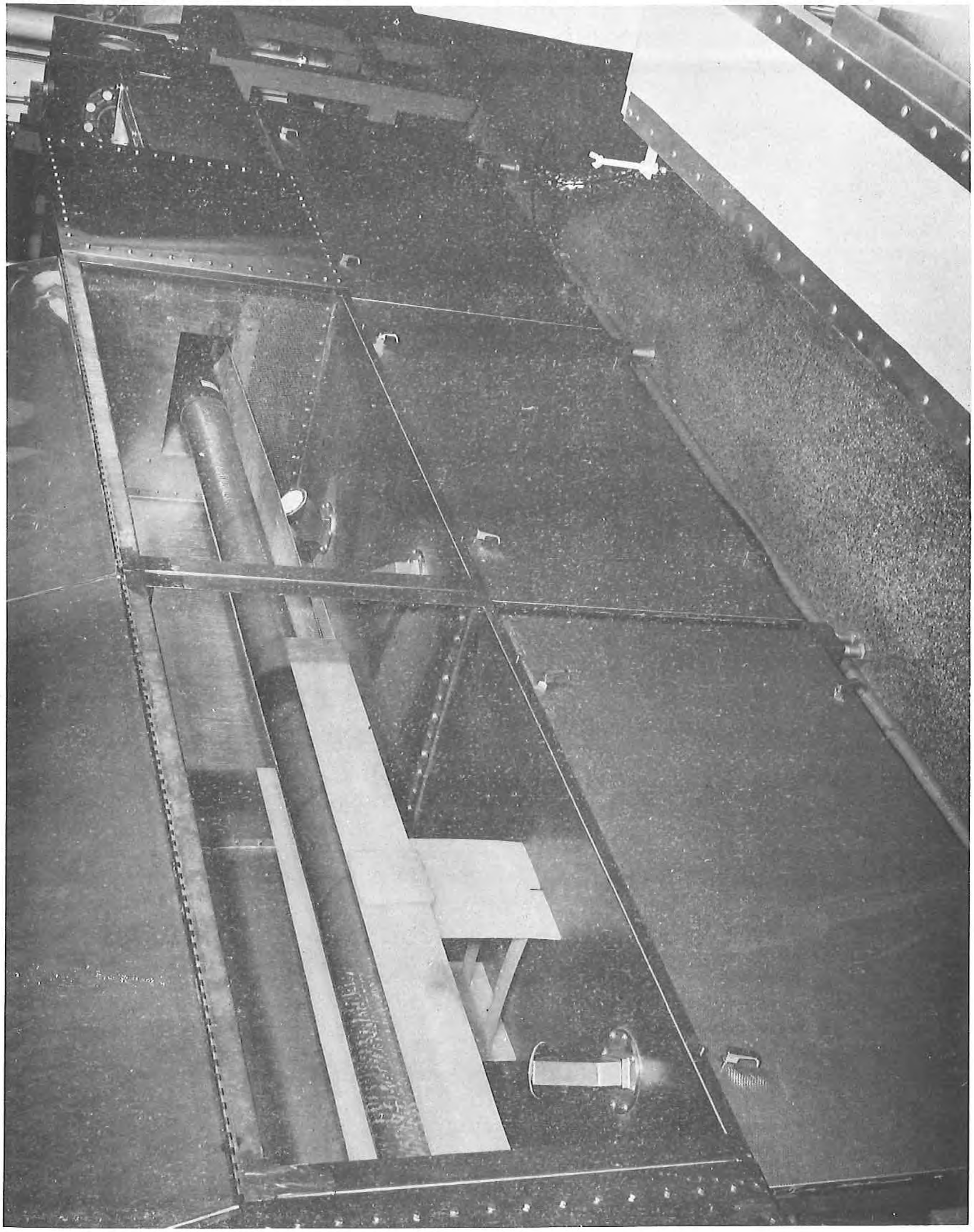

FIG. 8: View of epoxy-fiberglass tube in microwave cavity.

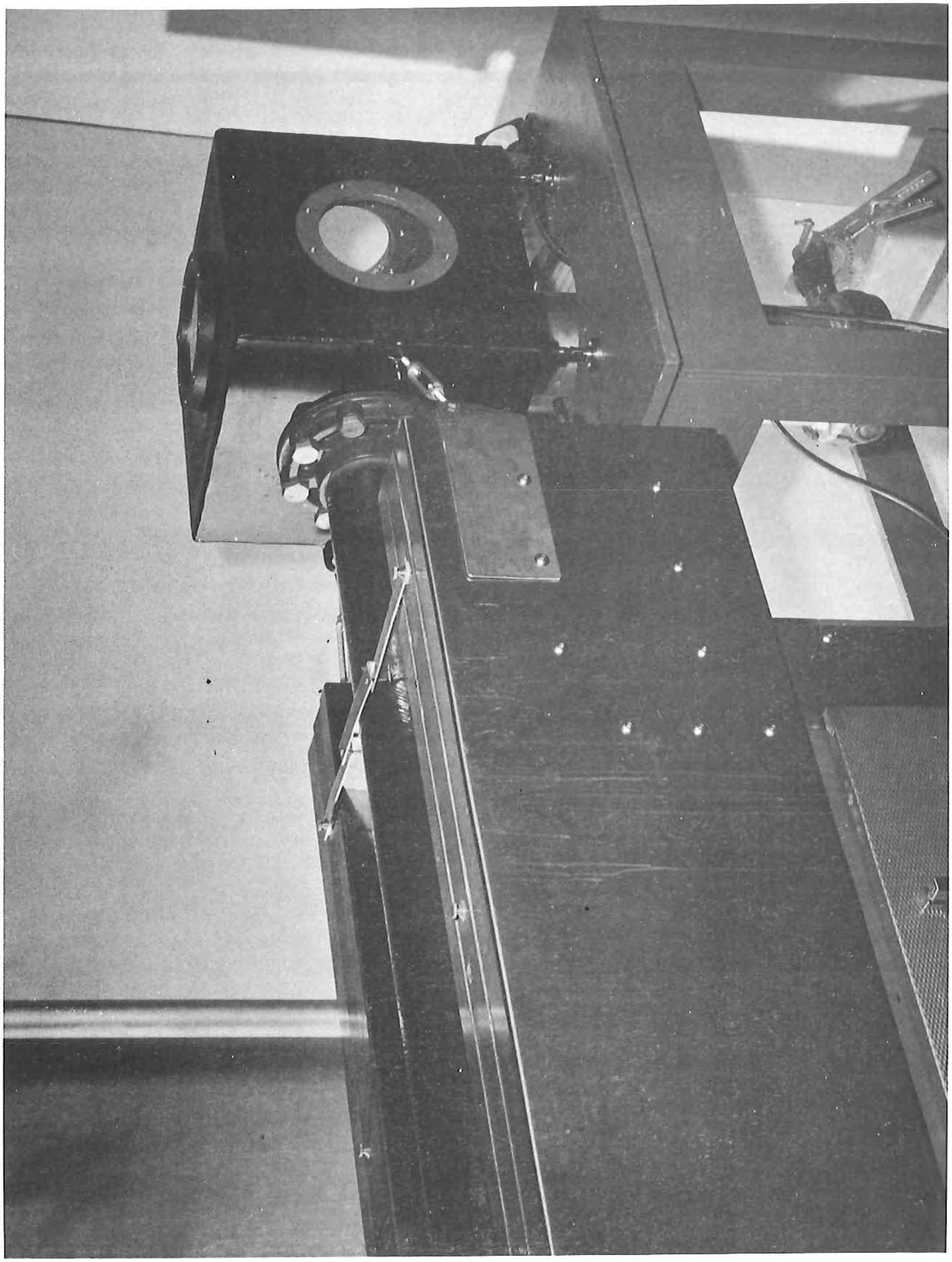

FIG. 9: View of exit end box.

FIG. 10: View of exit end box with control panel and cooling receiver attached below.

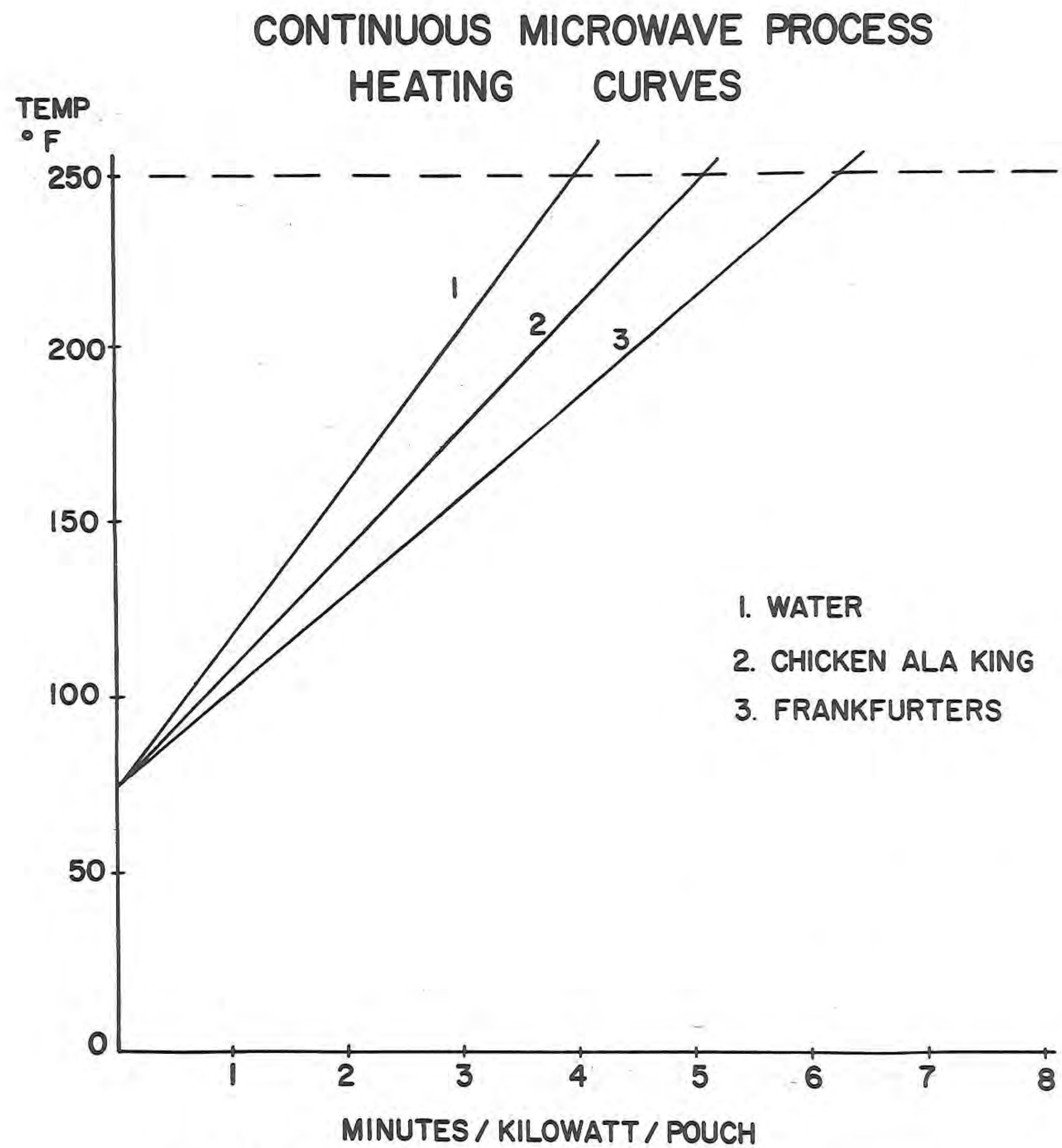

FIG. 11: Heating curves - continuous microwave processor.

MAXIMUM DESTRUCTION TIMES (MINUTES) OF BACTERIAL SPORES IN MOIST HEAT

	TEMPERATURE °F					
ORGANISM	212	221	230	239	250	257
B. ANTHRACIS	15	10				
B. SUBTILIS	17					
CL. BOTULINUM	330	120	90	40	10	
CL. SEPTICUM			5			
CL. TETANI	15	10				
CL. WELCHII	10	5				
THERMOPHILES	834	405	100	40	12	5
SOIL BACTERIA	1020	420	120	15	6	

TABLE NO. 1: Destruction times of bacterial spores to moist heat

CONTINUOUS PROCESSOR

FEED RATE	1 POUCH / MIN
TIME IN CAVITY	1-12 MIN
COOLING TIME	5 MIN
PRESSURIZATION TIME	1 MIN
OPTIMUM LOAD	2-5# (6-14 POUCHES)
BELT SPEED	0-7 FT / MIN
POWER RANGE	1.25-10 KW
OVER PRESSURE	0-40 LB/SQ IN
DIELECTRIC TEMP RISE	20-30° F
BELT LENGTH	24.5 FT
CAVITY BELT LENGTH	9.7 FT

TABLE NO. 2: Engineering characteristics of microwave processor

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13. ABSTRACT

Potentially, microwave power offers an opportunity to achieve a continuous and very rapid method of heat sterilization for food products. The capability of attaining temperatures of 250°F (121°C) or above in a matter of about 5 minutes as opposed to the present 50-60 minutes in a steam retort is expected to result in a product with greatly improved texture and flavor. In addition, there should be economies in the operation.

Previous work is reviewed briefly and the problems basic to the application of microwave power in food sterilization are discussed.

A continuous system for the thermal processing of food in plastic pouches has been developed in which over-riding air pressure is used to balance internal pressure and prevent pouch rupture. The pouches are filled with 6-8 ozs of food product, heat sealed and introduced through an airlock onto a conveyor inside a 5-inch I.D plastic(epoxy fiberglass) pipe which is located within a (Litton Model C-10S-2) microwave conveyor cavity. Microwave energy is supplied by four modular units generating a total of 10kW at 2450 MHZ. Conveyor speed and power level are regulated to provide the desired process time and temperature. Pouch cooling is accomplished either by a refrigerated platen under the final section of the conveyor or by immersion in a cold water reservoir. Pouches are over-packed after processing, in a barrier film (aluminum foil-plastic) laminate to provide protection and storage stability.

Several food products including frankfurters and chicken ala king have been processed in order to evaluate the system. Design and performance data are discussed and an evaluation is made of the future potential, both from the technical and economic points of view.

14. KEY WORDS	LINK A		LINK B		LINK C	
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Sterilization	8		8			
Food products	9		9			
Microwaves	10		10			
Microwave equipment	10		10			
Texture	4		8			
Quality	4		8			
Flavor	4		8			
Pouches (food)	5		9			